Nonlocal electrodynamics of superconductors applied to vortex lattices

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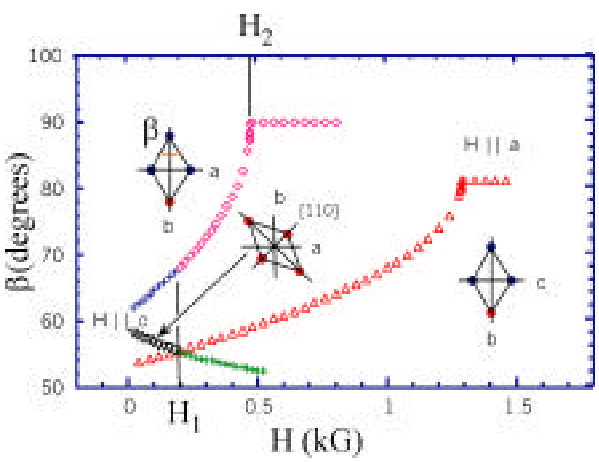
All applications of superconductors are related to their behavior in magnetic fields, which is quite unusual and different from that of normal metals. The field penetrates most of superconductors in the form of tiny flux filaments surrounded by circulating currents (vortices) and containing a certain amount of magnetic flux, “flux quantum”. The flux lines repel each other and usually arrange in periodic structures, vortex lattices. Understanding equilibrium properties of these lattices, their elasticity, and dynamics are of utmost importance for the basic physics and applications of superconductivity.

Recent neutron scattering experiments on borocarbide superconducting crystals (grown in Ames Laboratory) have revealed that the structure of flux-line lattices evolves with changing magnetic field and can even undergo phase transitions. A striking example of this behavior is when the triangular arrangement of vortices in small fields is transformed into a square lattice in high fields [1].

Understanding of this behavior came about after a so-called “nonlocal London theory” had been developed in Ames Laboratory by V. Kogan and collaborators, which provides a consistent account of the field, temperature, and purity dependence of the vortex lattice structure [2]. An example of predicted field dependencies of an apex angle for rhombic lattices in $LuNi_2B_2C$ is shown in the figure. Both gradual increase of the angle β with field and the transition at H_2 to a fixed high field structure, as well as a sudden reorientation at H_1 have been confirmed by neutron scattering experiments. Unlike previous models based on the high-temperature Ginzburg-Landau approach, the starting point for the nonlocal London theory is the microscopic theory valid at low temperatures, where vortex lattices are actually observed.

The nonlocal London theory is now a major theoretical tool in describing low temperature reversible magnetic behavior of a large class of superconductors (having high Ginzburg-Landau parameter) on a submicron scale (vortex lattices) as well as the macroscopic scale (magnetization) [3]. Implications of these ideas for irreversible properties are now under scrutiny in a few Labs (Bell, Oak Ridge, Bariloche).



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